Some criteria for evaluating physical modeling schemes in the context of music creation

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Some Criteria for Evaluating Physical Modeling Schemes in the context of Music Creation

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Abstract

In the context of the musical uses of Physically-Based Modeling, there is a need for generic algorithms and standard methodologies. The choice of such a Physically-Based Modeling scheme can dramatically impact the easiness in modeling, the quality of the produced sound, the relevance of the environments dedicated to musicians, etc. An overall understanding of the specificities of the various schemes available is needed. To that aim, this article proposes 10 criteria that summarize the main features an optimal physically-based modeling scheme should present, when dedicated to musical uses, and allow evaluating existing schemes in a multidimensional space. The article also points out the main properties of the major schemes along the criteria.

1. Introduction

The search for physical models able to synthesize musical sounds has developed since the 60's in parallel in Computer Music and Acoustics – though with various goals, see [1]. Physically-based models and Physically-Based Modeling (PBM) have now proved to be relevant in the context of music creation. However, they still hardly disseminate in the musical community. Further research is needed to empower musicians with physically-based modeling. This empowerment should ideally concern both quality in the sounds (as compared to signal-based synthesis techniques) and usability (i.e.: the possibility for a musician to practice physical modeling by himself, as a musical mean that may dramatically impact Computer Music).

In a musical context, it would not be sufficient to have a specific physically-based algorithm for every real sound object. Just as a number of signal-based sound synthesis techniques have been proposed over the years, various physically-based schemes, generic algorithms and standard methodologies have been introduced, capable of supporting models for various categories of sound sources. Examples are the wave-guide method, the mass-interaction scheme, the modal approach, etc.

Indeed, a scheme can potentially impact the whole creation process: overall sound quality, easiness in modeling, relevance of computer environments, etc. The design of a new scheme dedicated to musical uses, or the choice of an existing scheme for further scientific or musical investigations, is thus critical. As a result of a bibliographic study, this article aims at a better comprehension of the various benefits of the various physically-based modeling (PBM) schemes, by introducing 10 criteria dedicated to them. Depending on the needs, this set of criteria may stand for:

- A synthetic overview of the interests one may find in using Physical Modeling in the context of music creation.
- A summary of the feature that a hypothetical optimal Physically-Based Modeling scheme should present.
- A tool for evaluating the various existing schemes in a multidimensional space.

Our criteria C1 to C10 are categorized in the following in four sections, dealing respectively with computer efficiency, phenomenological interests, usability and environments for using the scheme. Throughout the article the most prominent properties of some of the major schemes along the criteria are commented. The schemes we consider are: (1) The traditional approach to physical modeling, which consists in first constructing a continuous-time model of a real structure with the laws of Physics, and secondly using a numerical analysis technique to obtain a run-able digital version; (2) The wave-guide scheme [2]; (3) The mass-interaction paradigm [3]; (4) The modal approach [4]. Due to the size of the article, no technical description of these schemes nor historical key point will be given. These will be found in the references given above, or in [5], for example.

2. Computer Efficiency criteria

C1. How Efficient is the Algorithm?

For a given richness of sound, or a given category of sound object, computational efficiency of two models based on two PBM schemes may be very different, in terms of both CPU and memory requirements. Computational efficiency influences the possibility of hardware implementation, the maximum complexity of a real-time simulation and the number of iterations in improving a "deferred time" model. Although computer power increases, it still remains critical, which is taken into account through the criterion C1.

The Wave-Guide scheme allows with no doubt particularly efficient models, since it focuses on the wave propagation phenomenon instead of modeling the matter itself. The mass-interaction scheme is not as efficient and the modal approach is intermediate.

3. Phenomenological criteria

C2. How Diverse are the Categories of Instruments?

This criterion C2 evaluates the diversity of the real sound structures (such as winds, strings, non linear musical instruments, etc.) and, more generally, of the real-world sound generation mechanisms that can be modeled in a relevant manner by implementing a given scheme. A scheme that maximizes this criterion may be particularly interesting for being the base of an environment for musical creation with a general purpose, provided it does not minimize the other criteria.

Since traditional Physics and Acoustics may apply to any category of sound production mechanisms, the traditional approach does maximize this criterion. The mass-interaction, wave-guide and modal approaches are then equivalent. The first is not well adequate to the modeling of wind resonators, and the lasts are dedicated to the modeling of linear structures, and can hardly be implemented in other cases.

C3. How Faithful are the Synthesized Sounds?

Many musicians, especially in popular music, consider the re-synthesis of the sound of real instruments as a very important feature. As a consequence, a scheme should ideally allow precision in both modeling and faithfulness in sound results. This is a crucial need when the aim is to propose digital instruments that could stand for their real counterpart.

Once again, since it can lead to models that are as precise as Physics allows, the traditional approach maximizes the C3 criterion. The other schemes, indeed, are less efficient regarding precision. However, the mass-interaction scheme may be considered as intermediate, since it inherently takes into account non-linearity, which is known to be particularly important in natural sounds.

C4. How diverse are the Categories of Phenomena that can be Obtained?

Physically-Based Modeling is often regarded as an approach to sound synthesis, which major interest is the quality of the sounds it leads to. This is reducing. Physical models, indeed, can potentially address categories of phenomena that are still relevant in the context of music creation, though not directly related to sound. We illustrate this idea through 3 examples.

First, visual representations of the simulations have proved to provide a major help in understanding the models' dynamic properties [6]. However, while some schemes naturally lead to a relevant visual output, others don't.

Second, by promoting a representation of the dual concepts of forces and positions, physically-based models allow a particularly direct interconnection of the model with haptic interfaces. These have proven their interest in the context of real-time playing. However, it may be more or less easy to obtain a model able to generate relevant gesture feedbacks, depending on the scheme used.

The third point is a bit more complex.

Recently, Cadoz introduced an approach to musical composition entirely based on the mass-interaction scheme [7]. As Cadoz explains, one can obtain a succession of sound events rather an isolated sound by assembling in a complex structure both high frequency models and low frequency models. Cadoz demonstrated that this approach can be extended dramatically. His experimental piece "pico..TERA" is made of a single model with thousands of masses and tens of different "objects" of different scales interacting. 5 minutes of music is then obtained by executing this model without any external interaction nor post-treatment. This "compose (with) physically-based models" process presents various major advantages. First, low frequency models are slightly perturbed in a natural manner by retroaction from sound models. Thus, the sound events generated do present convincing short-term evolutions, expressiveness and musicality, such as changes in a rhythm or in the timbre of successive musical events – somehow as a musician would do. Second, the process proves that physical modeling makes it possible to meld within a single paradigm both sound synthesis and computer-aided composition.

Given the three points above, in the context of musical creation an optimal scheme should allow the synthesis of various categories of sensible phenomena, including haptic and visual ones. It should also not be dedicated to sound structures but, more generally, to the modeling of every sort of objects and to the simulation of the instrumental gesture. These awaited features are taken into account in the C4 criterion.

Existing schemes are not equivalent regarding this criterion. Since they model respectively wave propagation and modal behavior, the wave-guide and modal scheme approaches are hardly relevant for the modeling of non-oscillating physical phenomena. The traditional approach, as for it, may hardly allow a visual representation of the model during simulation. Indeed, the mass-interaction approach probably maximizes C4.

4. Usability criteria

Though its phenomenological interests, physically-based modeling hardly encounters an important success amongst the musical community. Indeed, researchers often consider that musicians should not be in charge of the modeling itself, since it is usually assumed to be difficult and to require a scientific knowledge they rarely possess. Thus, within most of the environments dedicated to musicians the modeling process tends to be hidden to the user. From our point of view, a different approach should be encouraged.

Though musicians are not commonly confronted in an intellectual manner with the notions of inertia, damping, physical interaction, etc. all these notions are intuitively prehensile through our body and our everyday life. Our experience, especially with the numerous users of the GENESIS environment [8], proves that modeling may be accessible to every one, based on what we call an intuitive 'physical thought'. Moreover, practicing physically-based modeling can be particularly interesting for a musician: among other lexical fields, the musical vocabulary employs physical concepts, such as energy, waves, motion, force, etc. – concepts that are particularly well addressed by PBM.

Thus, an important challenge for the coming years in the field would be to search for the necessary features, tools, etc. that would empower musicians with the practice of PBM. However, while modeling, a musician would not put into practice the physical knowledge of a scientist. His process may be nothing but empirical and intuitive. *Usability* of a given scheme is therefore very important. The three next criteria aim at evaluating whether or not a scheme is a good candidate for being implemented by a musician himself.

C5. How Robust is Sound 'Physical Plausibility'?

As discussed in criteria C3, one may seek faithfulness in the synthesized sounds by designing or using a physical model. But another approach is possible. By assembling basic building blocks of a scheme, one may obtain a model able to synthesize sounds that have absolutely no real counterpart – so that a physically-based model can be considered as a "musical reality generator" [5]. Since it implements physically-based algorithms, we can hope that the sound produced by such a model would present a set of subtle dynamic variations among perceptual parameters that lead the listener to think it was produced in some physical manner – though unrealistic. This is what we call *physical plausibility* of a sound. A sound may be far from evocating any real acoustic source while still being "plausible".

Indeed, among other roles, we know that hearing is innately tied to inquiry into the physical origin of a sound. Consequently, synthesized sounds are more easily accepted by listeners and have a better profile when they lead the subject to think they were produced by an hypothetical object [9]. In other words, there is a need for plausible – though unrealistic – sounds in the context of music creation.

Though physical modeling is, generally speaking, appropriate for the synthesis of plausible sounds, the various scheme are not equivalent to that aim. Certain schemes do not naturally lead to 'plausible' sounds when the models are not designed carefully with reference to a real object. The robustness of sound "physical plausibility" is thus a particularly important criterion. A scheme that is not robust will hardly be relevant for being used by a musician with an empirical approach.

The modal approach probably minimizes the robustness criteria, since the 'physical plausibility' of the synthesized sounds hardly depends on the chosen set of modes. On the contrary, the mass-interaction is particularly interesting regarding this C5 criterion: apart in a few peculiar cases, a network of masses and interactions will behave physically and sound 'plausible', no matter how it was constructed.

C6. How Modular is the technique?

Modularity has been regarded as an important feature since the very beginning of Sound Synthesis. As said Mathews, modularity is necessary to obtain at the same time generality, power and simplicity [10]. In the context of physically-based modeling, modularity may be approached through various points of view: existence and meaningfulness of basic modules and composing rules, size of the basic modules, possibility of an incremental modular process rather than a one-shot modeling, etc. They altogether represent this criterion.

The wave-guide, mass-interaction and modal schemes are modular – whereas the traditional approach is not. However, one can notice that the basic modules of the modal approach necessarily model a whole structure, and the delay filter of wave-guide scheme is hardly physically meaningful by itself. Indeed, the modularity criterion is maximized by the mass-interaction paradigm.

C7. How Intuitive and Effective is the Mental Model?

From a cognitive point of view, the "user's mental model" (or conceptual model) is the representations the user builds in his mind regarding a system. The use of a system is not based on its real properties, but on the user's mental model. A good mental model should let the user anticipate the results of his action and facilitate explorations. The mental model associated with a PBM scheme may hardly depend on the user's knowledge of Physics. Nevertheless, a scheme can be easier or more difficult to elaborate and implement, depending for example on the intuitiveness of the notions it displays. Many sorts of mental models may be relevant for a musician. However, we consider that the mental model will be more interesting if it let the user build and handle his models as if they were real objects, and not as a set of equations or theoretical constructions. As a consequence, an optimal scheme should promote an "impression of reality" when used.

As evidence, the mental model associated with the traditional approach may hardly be relevant for a musician. Conversely, the mass-interaction paradigm is of interest regarding the C7 criterion: each of its basic module can be easily internalized by any user as representations of very basic objects, and remain pertinent for the human senses; and the effect of a module in a model is usually meaningful. The modal approach also maximizes this criterion, though for other reasons: since modal data are collections of frequencies, decay time and amplitude weightings, the scheme can be approached with the signal-based vocabulary. This enables a relevant mental model that proved to be efficient for users that are accustomed to the additive synthesis technique, though not directly based on intuitive physical concepts.

C8. How Deep is the Modeling Process Enabled?

As proposed by Cadoz [11], three categories can be distinguished among the models we can build: phenomenological, functional and structural. The recording of a sound is, for example, a phenomenological model. A signal-based model for the re-synthesis of the sound is a functional model. When one does not consider the observed phenomenon but the object that generated it, decomposing recursively this object in smaller interacting objects, and proposing a model for each of the latter, a structural modeling process is performed. As a matter of fact, says Cadoz, a physically-based model is nothing but the result of some structural modeling process. The deepness of a model is the point at which the structural decomposition is stopped and replaced by a functional (or even phenomenological) approach. Our C8 criterion then consists in evaluating the deepness of the modeling process associated with the scheme.

It is not a priori necessary to perform a deep modeling in order to maximize the phenomenological precision criterion C3, particularly in the case of isolated sound events. However, a scheme that enables a deep modeling process tends to be easier to use. It is usually modular and, since the basic modules are smaller, they may be more comprehensible for the user.

5. Criteria Regarding the Environments

C9. How Efficient are Generation Algorithms?

The C9 criterion studies whether or not there exist algorithms for parameter estimation or model generation for the re-synthesis of a set of perceptual parameter (frequency, timbre, etc.), and evaluates their effectiveness. Such tools would establish a connection between the signal (or phenomenological) space and the physical model space, and thus they can help in designing a model. However, they should be used carefully: one of the major interest of physically-based modeling is to be found in the shift in the mental approach to music creation it calls for, which may be reduced by generalizing these tools.

At the moment, the most powerful generation algorithms are available in the context of the modal and wave-guide paradigms. Research is in progress for other schemes (see [8] for example).

C10. Is an Environment dedicated to Musicians Possible?

As commonly argued in Human-Computer Interaction, the 'end-user oriented' part of an environment should not be seen as an opportunity to circumvent shortcomings in usability of the 'functional core', but should be designed in order to provide a clear-as-possible interface to the 'functional core'. Translated into our context, this idea shows that a given scheme may or may not be well-adapted for implementation in a musician-oriented environment, depending on its 'innate usability'. This is pointed out by our C10 criterion, which may be regarded as a summary of many of the above criteria.

The grid of criteria above tends to prove that the mass-interaction paradigm is particularly relevant for the building of general-purpose environments. However, other schemes may with no doubt be implemented with success, depending of some specific musical needs. At the moment, environments are available for the modal and mass-interaction schemes [3, 8]. Research are in progress for the wave-guide approach.

6. Conclusions

In the context of musical creation, the choice of a physically-based modeling scheme is important whatever the aims pursued can be. A scheme impacts the computer efficiency of the models, the quality and musicality of the produced sound, the diversity of the possible phenomena, the possibility of the practice of physically-based modeling by the musicians themselves, etc.

The 10 criteria we proposed focused on processing cost, on phenomenological interests, on usability and on the existence and validity of software environments. They show that the various schemes may be more or less adequate, depending on the user needs. More generally, we wish they could be useful for a better understanding of the specificities of the various schemes.

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